Extreme Space Weather Events and Charging Hazard Assessments in Lunar Environments

Joseph I. Minow
NASA, Marshall Space Flight Center
Huntsville, Alabama 35812 USA

Linda N. Parker and William C. Blackwell, Jr.
Jacobs Engineering, ESTS Group
Huntsville, Alabama 35812 USA

37th COSPAR Scientific Assembly
Montreal, Canada 13-19 July 2008

Introduction

- **Space systems on lunar surface or in lunar orbit exposed variety of plasma environments including**
  - Solar wind
  - Magnetosheath
  - Magnetosphere

- **Surface potentials in these environments have been determine theoretically, experimentally to be on the order of [*Manka*, 1973; *Whipple*, 1981; *Halekas et al*., 2002; *Halekas et al*., 2005a,b]**
  - Day ~10's volts positive
  - Night ~10's to 100's volts negative, extremes to ~kV values

- **Charging environments at night in lunar orbit or on the lunar surface may contain charging risks similar to geostationary orbit during extreme space weather events**

- **Today's presentation is preliminary results from an investigation to:**
  - Examine free field plasma environments relevant to lunar orbit to determine range of mean and extreme conditions
  - Scale free field environments to lunar wake
  - Screen data set for extreme wake charging environments intended for use as input to quantitative 3-D spacecraft charging codes

Surface Charging Current Balance

- Time dependent current balance

$$\frac{dQ}{dt} = \frac{d\sigma}{dt}A = C\frac{dV}{dt} = \sum_k I_k = 0 \quad \text{at equilibrium}$$

- Currents

$$\frac{dQ}{dt} = \sum_k I_k =$$

$+I_i(V)$ **incident ions**

$-I_e(V)$ **incident electrons**

$+I_{bs,e}(V)$ **backscattered electrons**

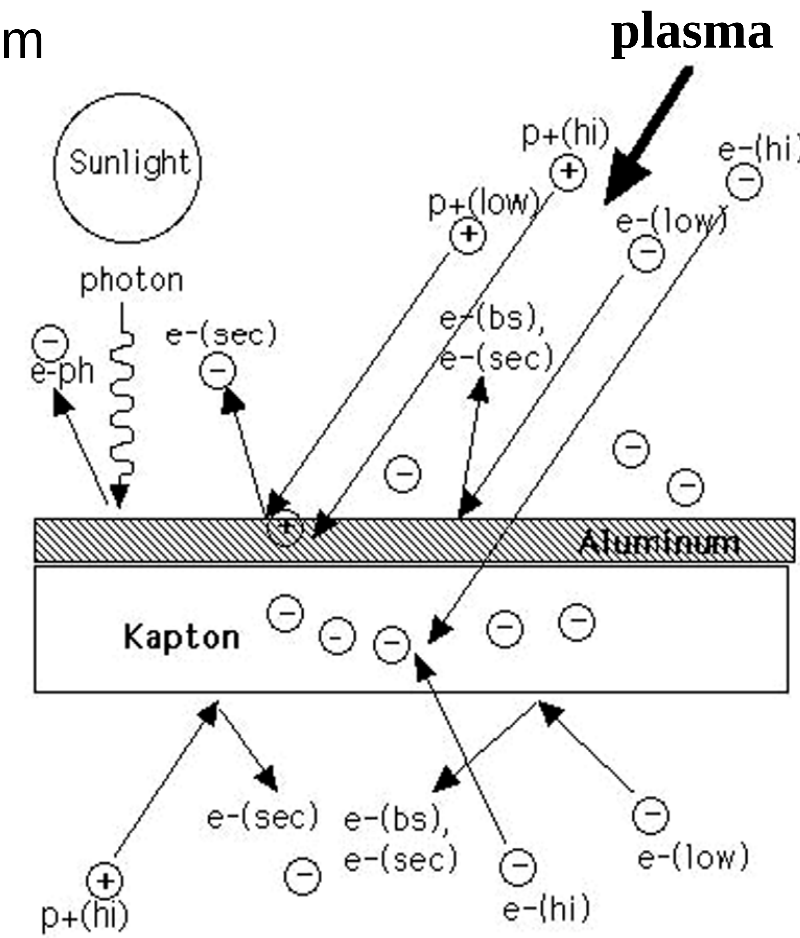
$+I_c(V)$ **conduction currents**

$+I_{se}(V)$ **secondary electrons due to I_e**

$+I_{si}(V)$ **secondary electrons due to I_i**

$+I_{ph,e}(V)$ **photoelectrons**

$+I_b(V)$ **active current sources (beams, thrusters)**



(*Garrett and Minow*, 2004)

Surface Potential

- Potential at equilibrium approximately

$$\phi = -\frac{kT_e}{e}\ln\left[\left(\frac{T_e}{T_i}\frac{m_i}{m_e}\right)^{1/2}\left(\frac{n_e}{n_i}\right)\right]$$

$$\sim -\frac{kT_e}{e}3.74$$ with $T_e \sim T_i$, $n_e \sim n_i$, and $m_i/m_e \sim 1800$

- Neglects
  - Secondary electron emission (best for high energy electrons)
  - Photoemission (absent in lunar wake)
  - Ram flux (only interested in wake environments)

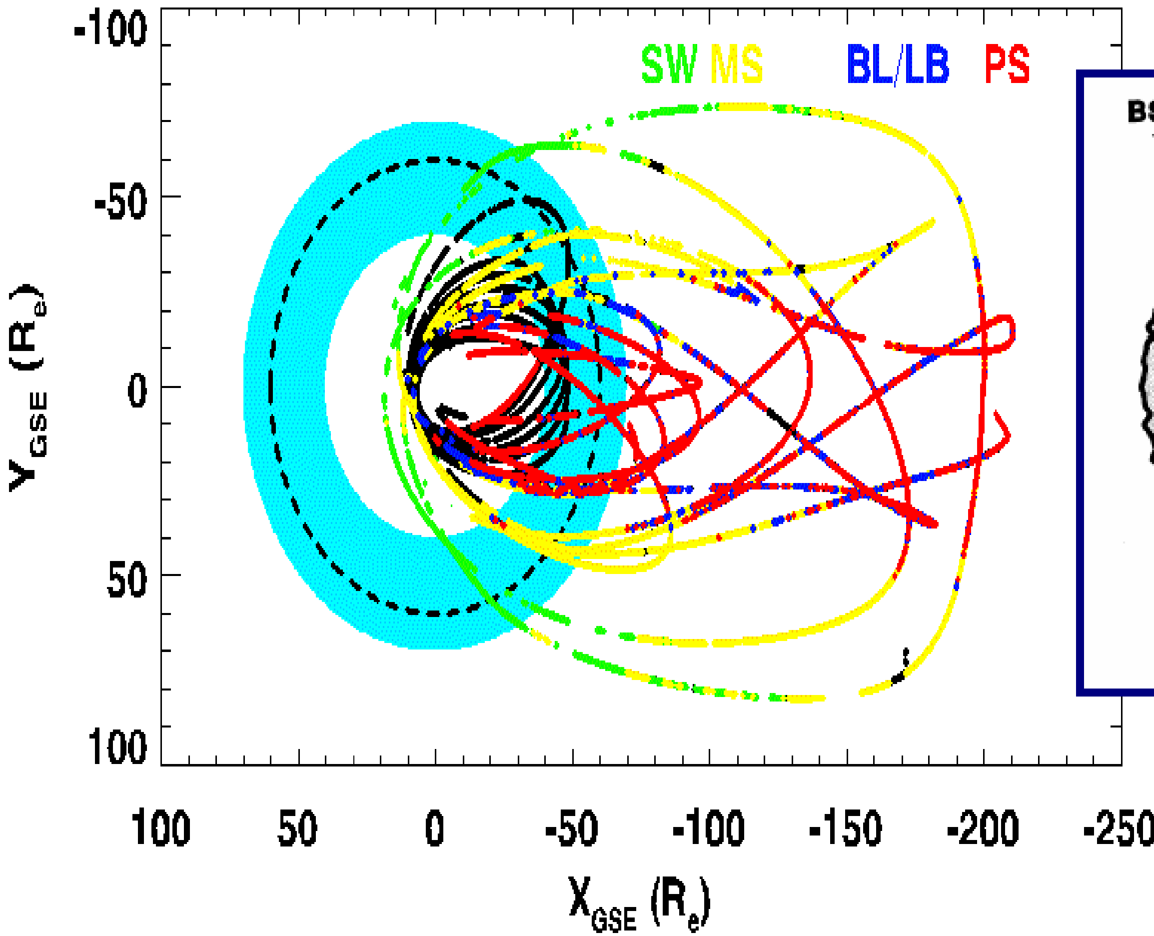
- Closed form potential solution provides convenient technique for rapid screening of large sets of plasma moments
  - Preserves N-T correlations
  - Not intended to provide quantitative computation of spacecraft potential

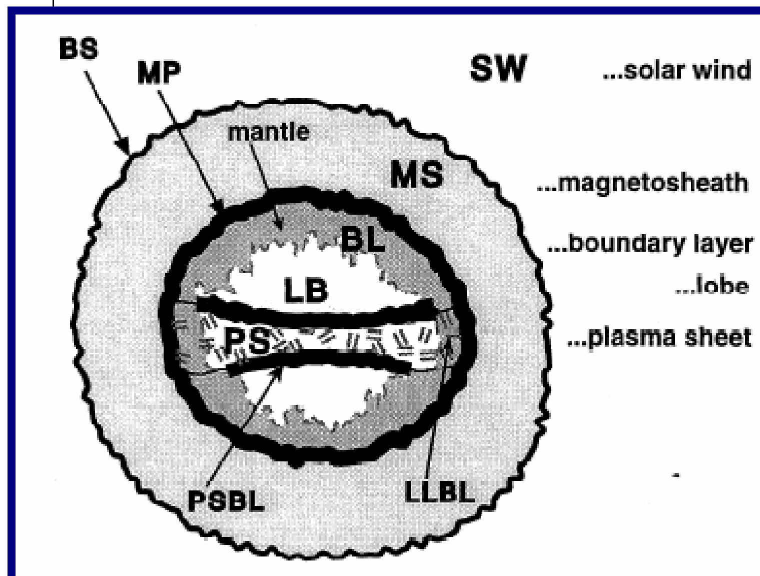
Data Set

Geotail: 10 Re x 210 Re, near ecliptic

--Comprehensive Plasma Instrument/ Hot Plasma Analyzer (CPI/HPA) — **University of Iowa**

--Geotail plasma regime identification — **EPIC Science Team, JHU/APL**

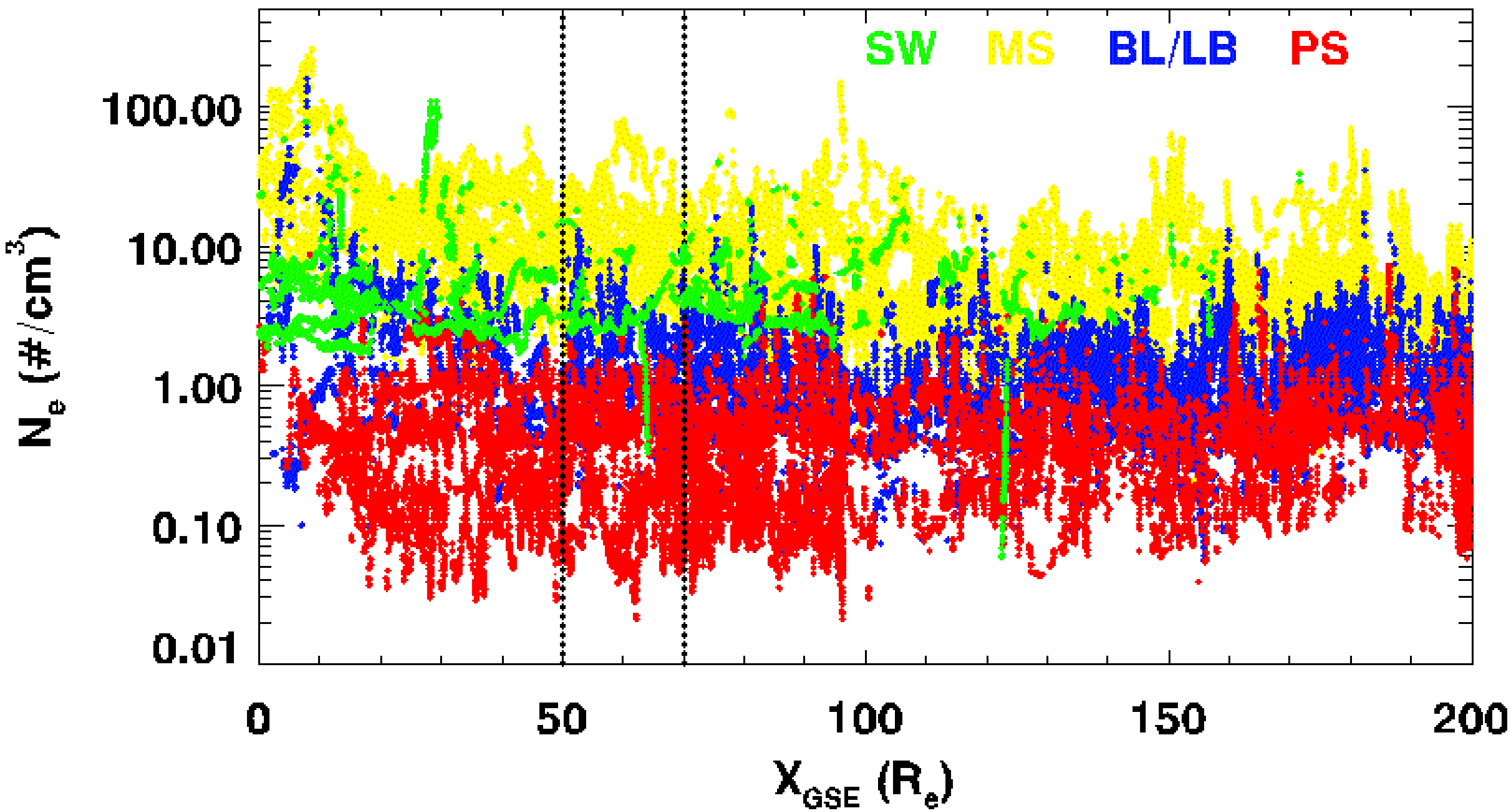




Magnetotail Plasma Regime Identification

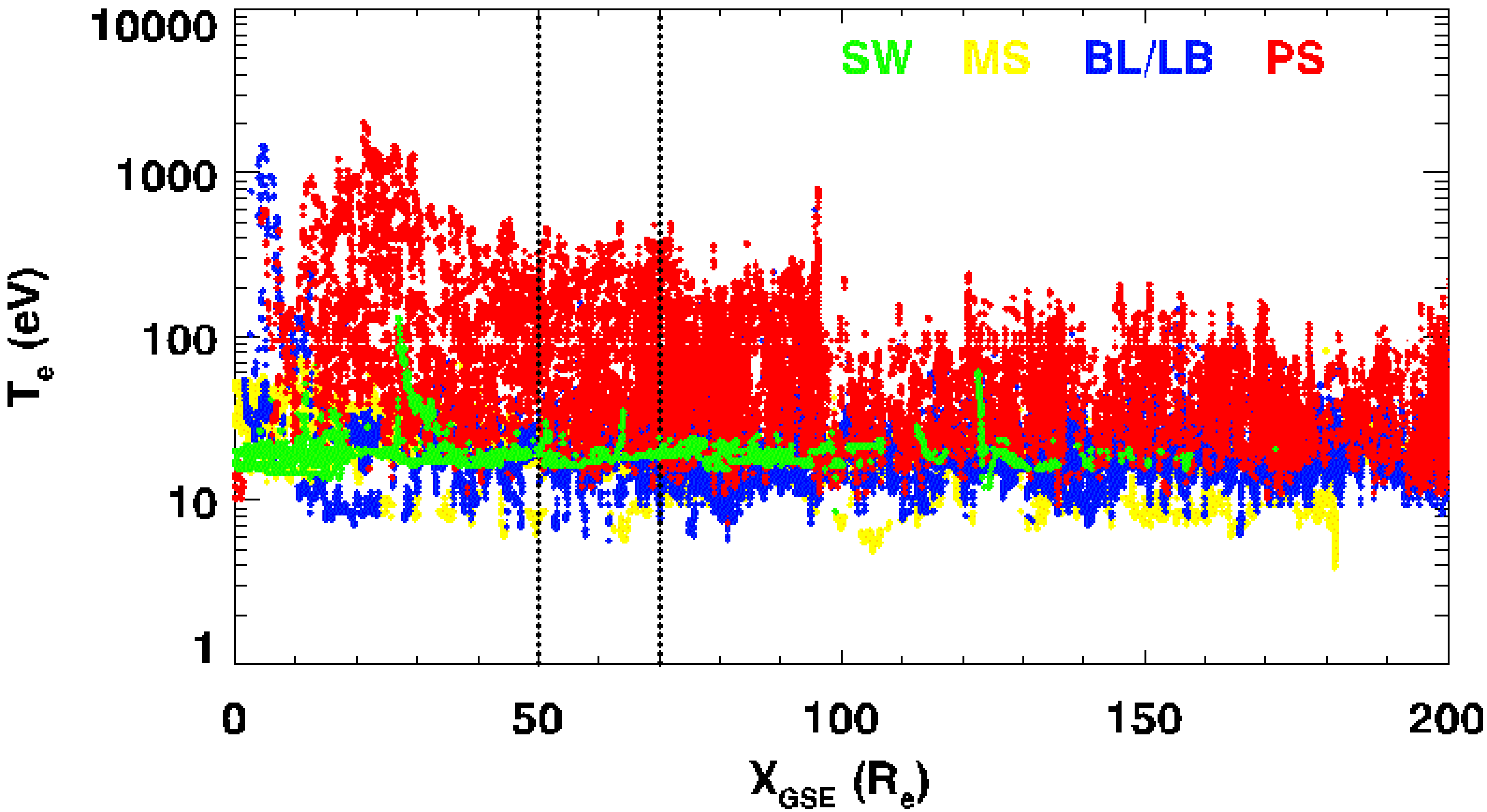
[*Christon et al*. 1998; *Eastman et al*., 1998]

N_e versus Radial Distance



~15 point median filter

T_e versus Radial Distance



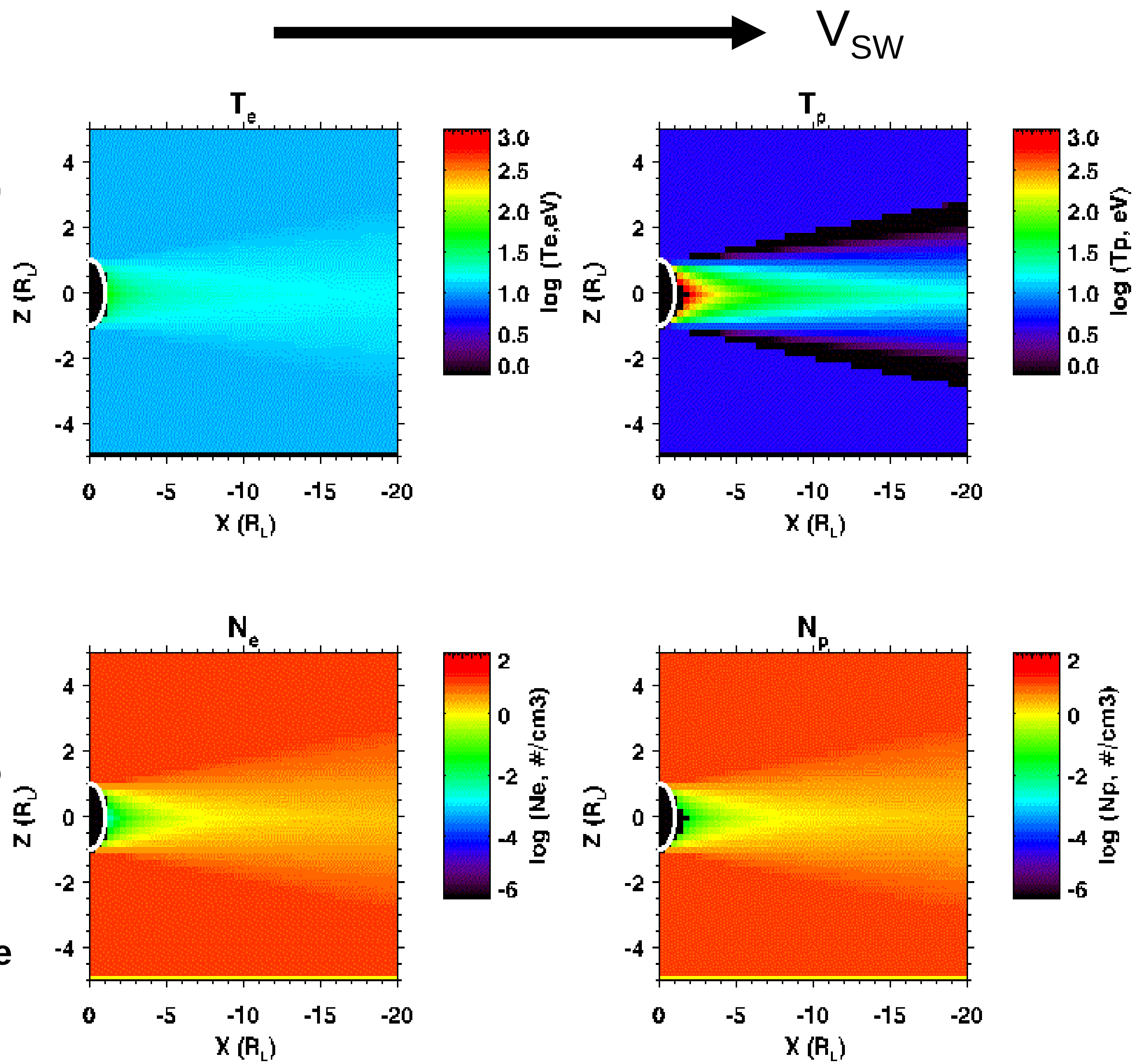
15 point median filter

Lunar Wake Model

- **First order estimate for wake plasma environments from analytical wake models**
  - **Electrons [*Halekas et al*., 2005]**
  - **Ions [*Samir et al*., 1983]**

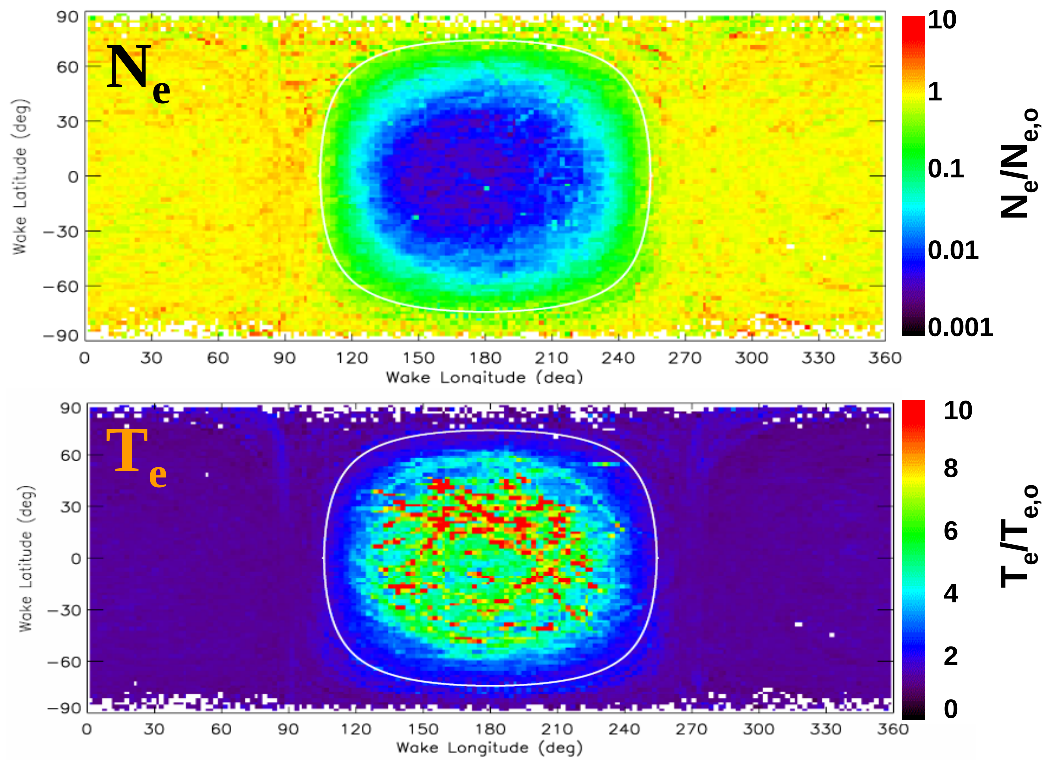
- **Model applicable to plasma expansion region into wake, distant lunar wake regions**

- **Deep wake near Moon requires further analysis**
  - **Wake model overestimates plasma density compared to in-situ measurements**
  - **Models inadequate to establish charging design environments which must be traceable to measurements**



Lunar Prospector Observations

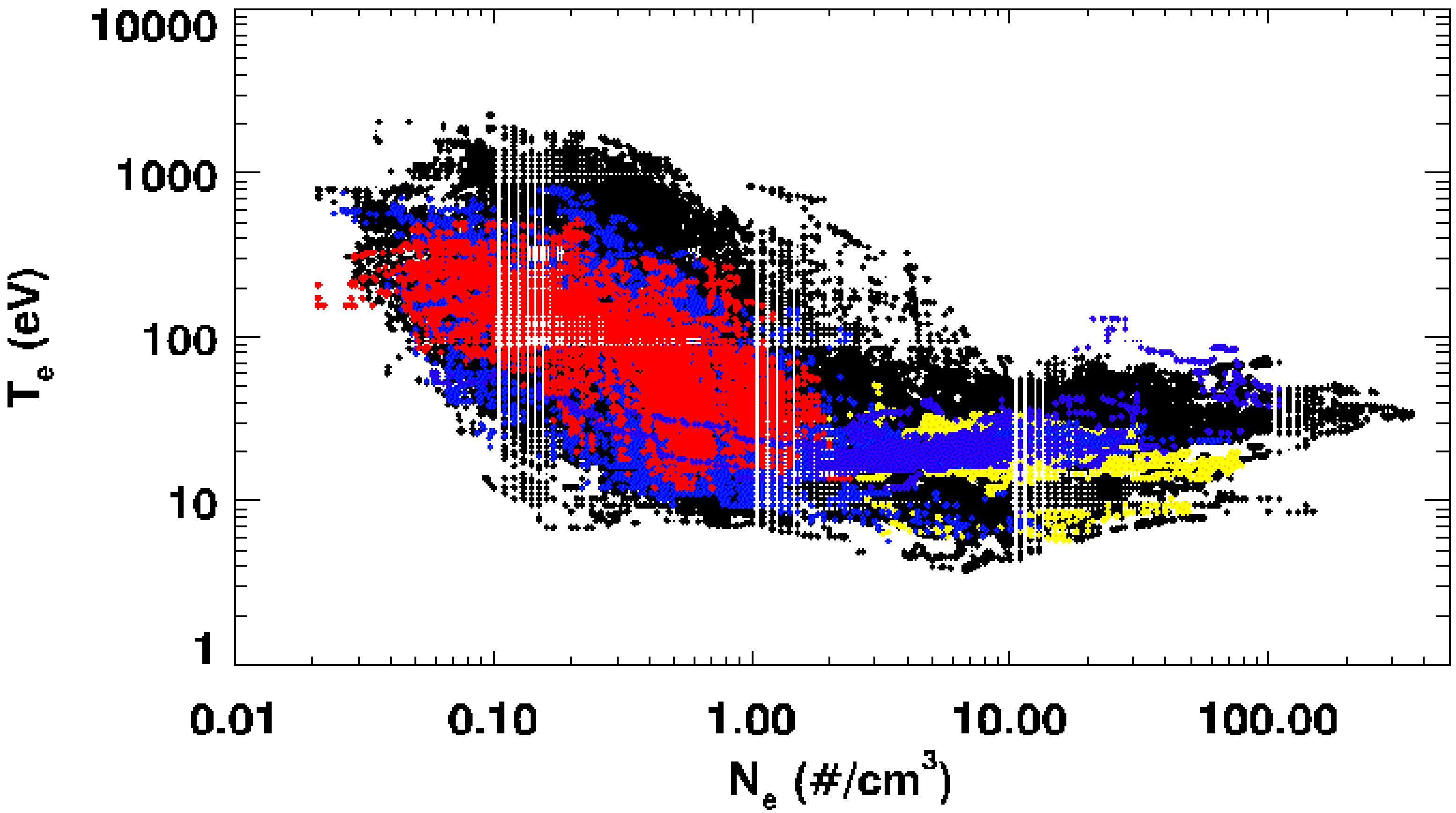
- **Most extreme charging environments (high electron temperature) in lunar system occur in lunar wake**
- **Photoemission is absent and plasma currents dominate charging process**
- **Lunar Prospector electron measurements establish wake parameters relative to free field environment [*Halekas et al.*, 2005]**
- **Geotail environments scaled to wake conditions using**
  - **N_e / $N_{e,o}$**
  - **T_e / $T_{e,o}$**
  - **Assume $N_i \sim N_e$**
    $T_i \sim T_e$



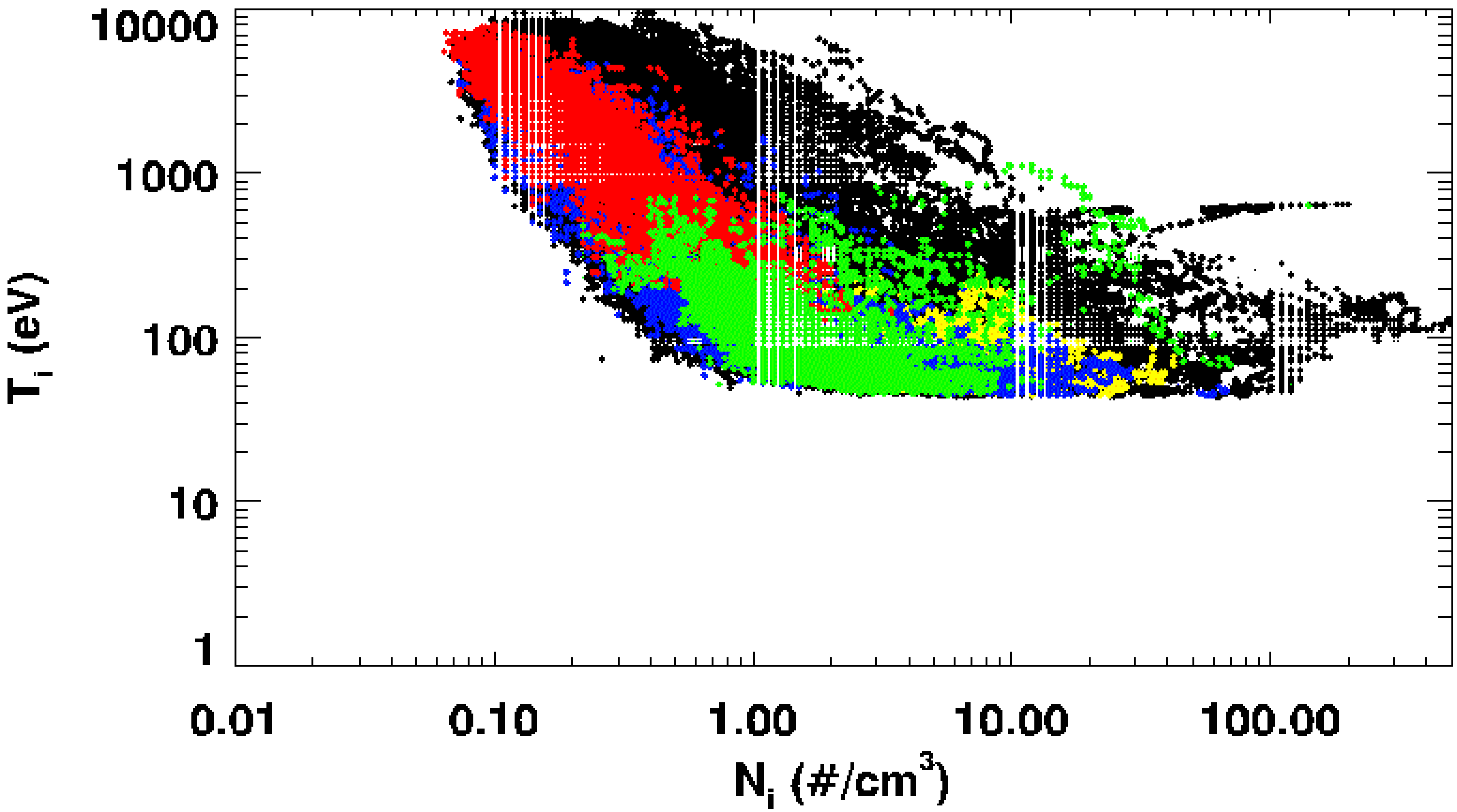
[*Halekas et al*. 2005b]

Environment	$N_e/N_{e,o}$	$T_e/T_{e,o}$
Free field	1	1
Wake 150º	0.005	7.6
Wake 180º	0.003	4.5

Free Field Ne-Te Correlations



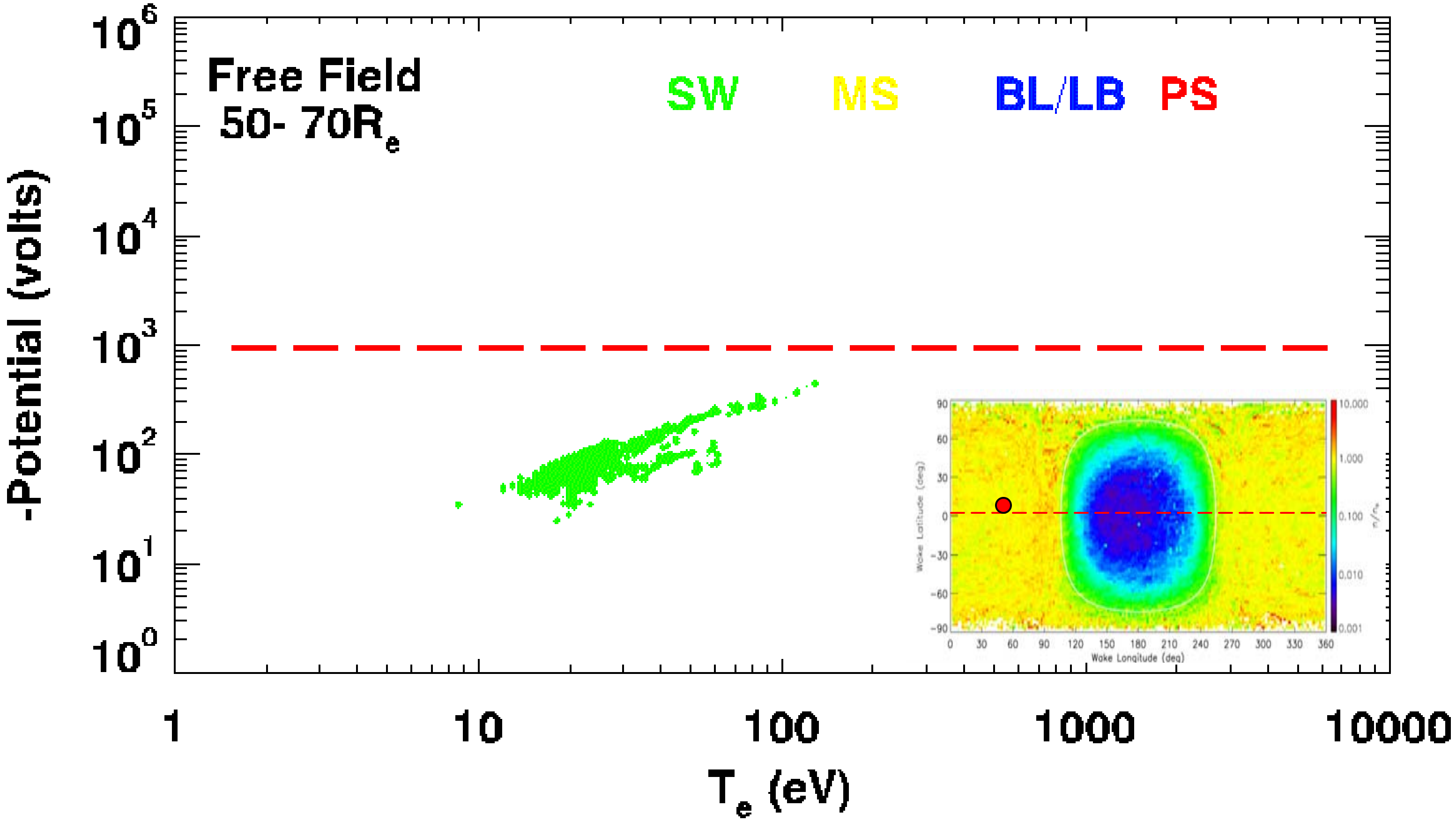
Free Field Ni-Ti Correlations



Free Field "Eclipse" Potentials

50-70 R_e

$$\phi = -\frac{kT_e}{e}\ln\left[\left(\frac{T_e}{T_i}\frac{m_i}{m_e}\right)^{1/2}\left(\frac{n_e}{n_i}\right)\right]$$

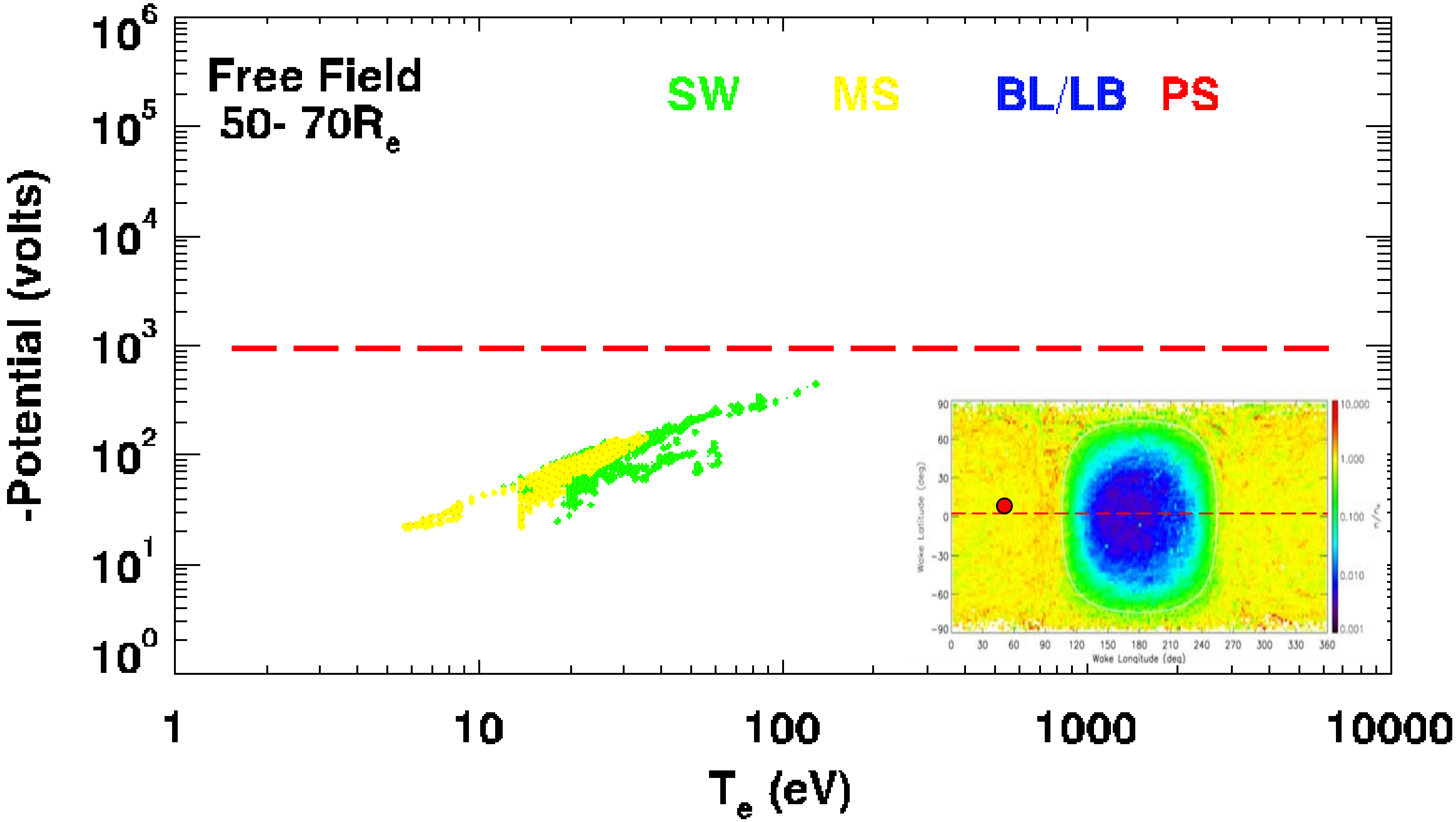


37th COSPAR Scientific Assembly, Montreal, Canada 13 – 19 July 2008

Free Field "Eclipse" Potentials

50-70 R_e

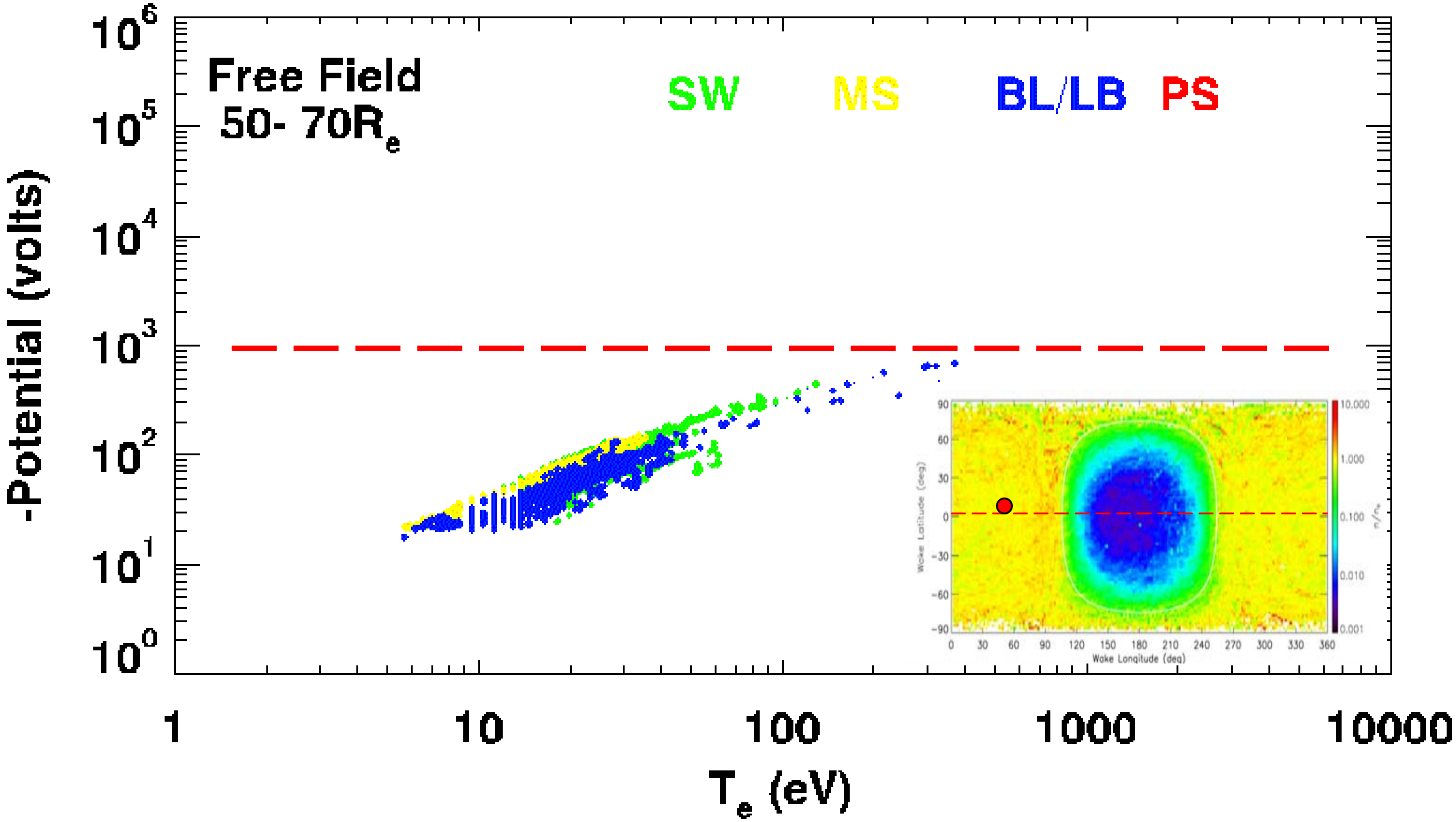
$$\phi = -\frac{kT_e}{e}\ln\left[\left(\frac{T_e}{T_i}\frac{m_i}{m_e}\right)^{1/2}\left(\frac{n_e}{n_i}\right)\right]$$



Free Field “Eclipse” Potentials

50-70 R_e

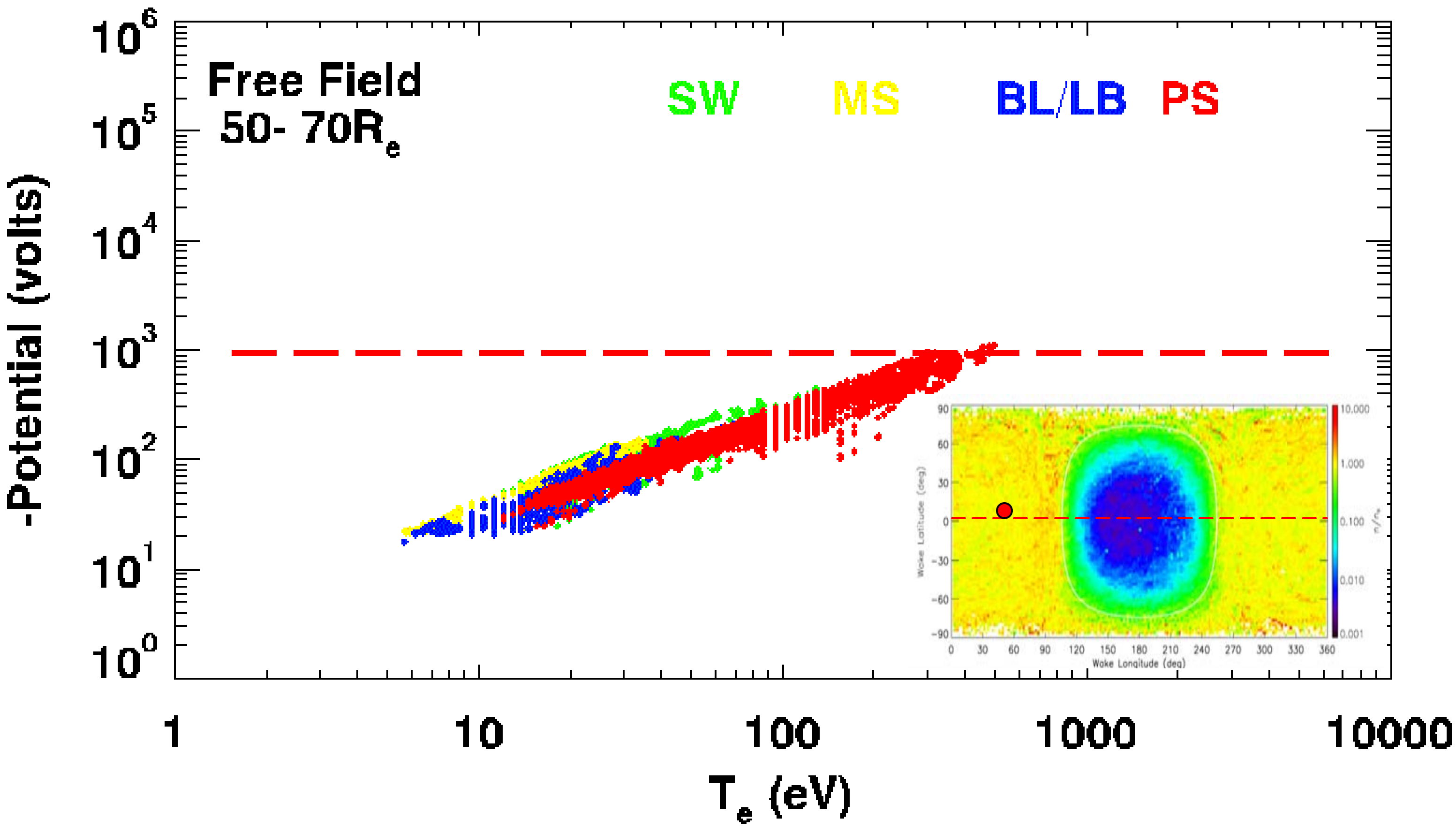
$$\phi = -\frac{kT_e}{e}\ln\left[\left(\frac{T_e}{T_i}\frac{m_i}{m_e}\right)^{1/2}\left(\frac{n_e}{n_i}\right)\right]$$



Free Field “Eclipse” Potentials

50-70 R_e

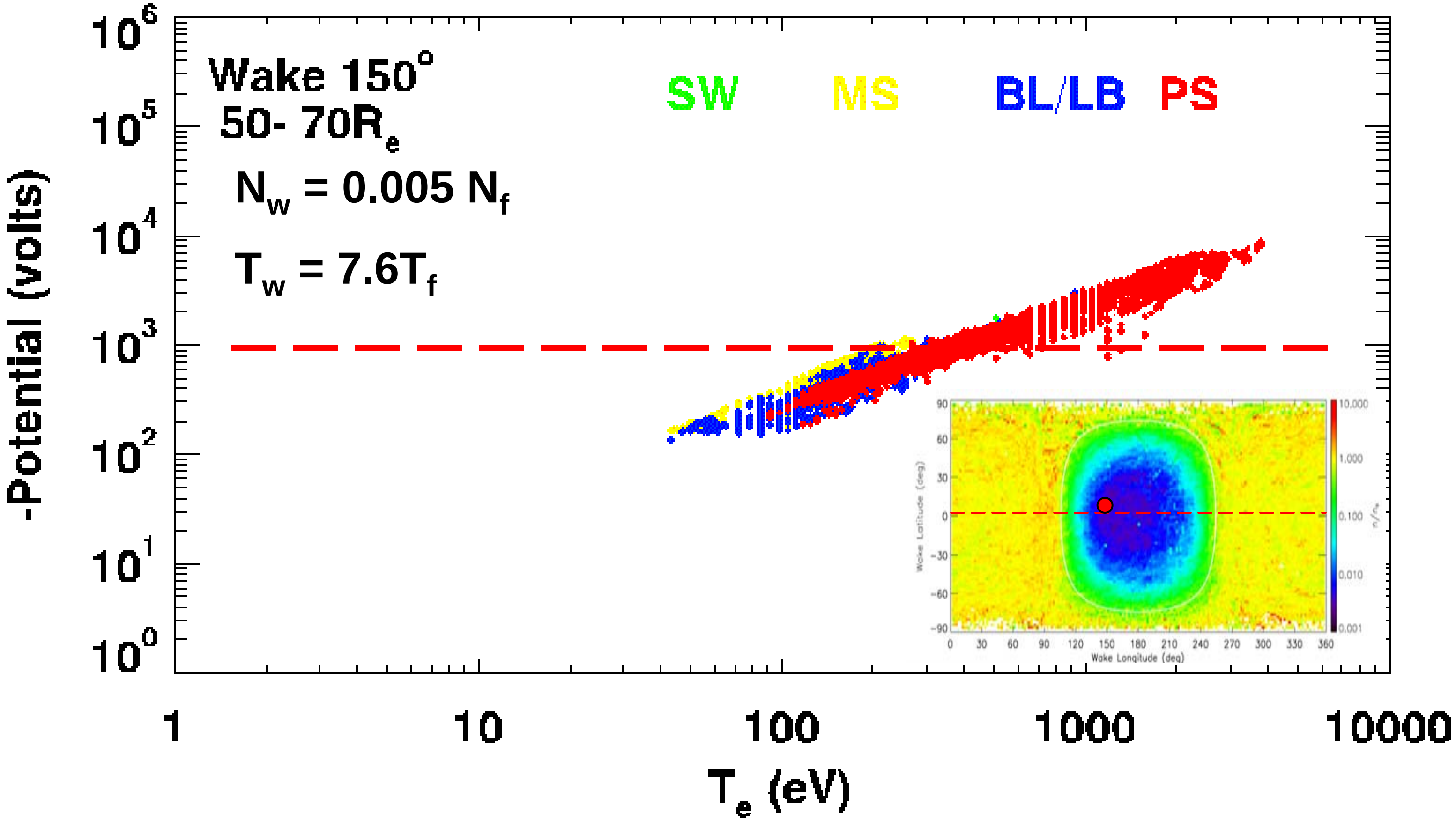
$$\phi = -\frac{kT_e}{e}\ln\left[\left(\frac{T_e}{T_i}\frac{m_i}{m_e}\right)^{1/2}\left(\frac{n_e}{n_i}\right)\right]$$



Wake Potentials: 150º

50-70 R_e

$$\phi = -\frac{kT_e}{e}\ln\left[\left(\frac{T_e}{T_i}\frac{m_i}{m_e}\right)^{1/2}\left(\frac{n_e}{n_i}\right)\right]$$



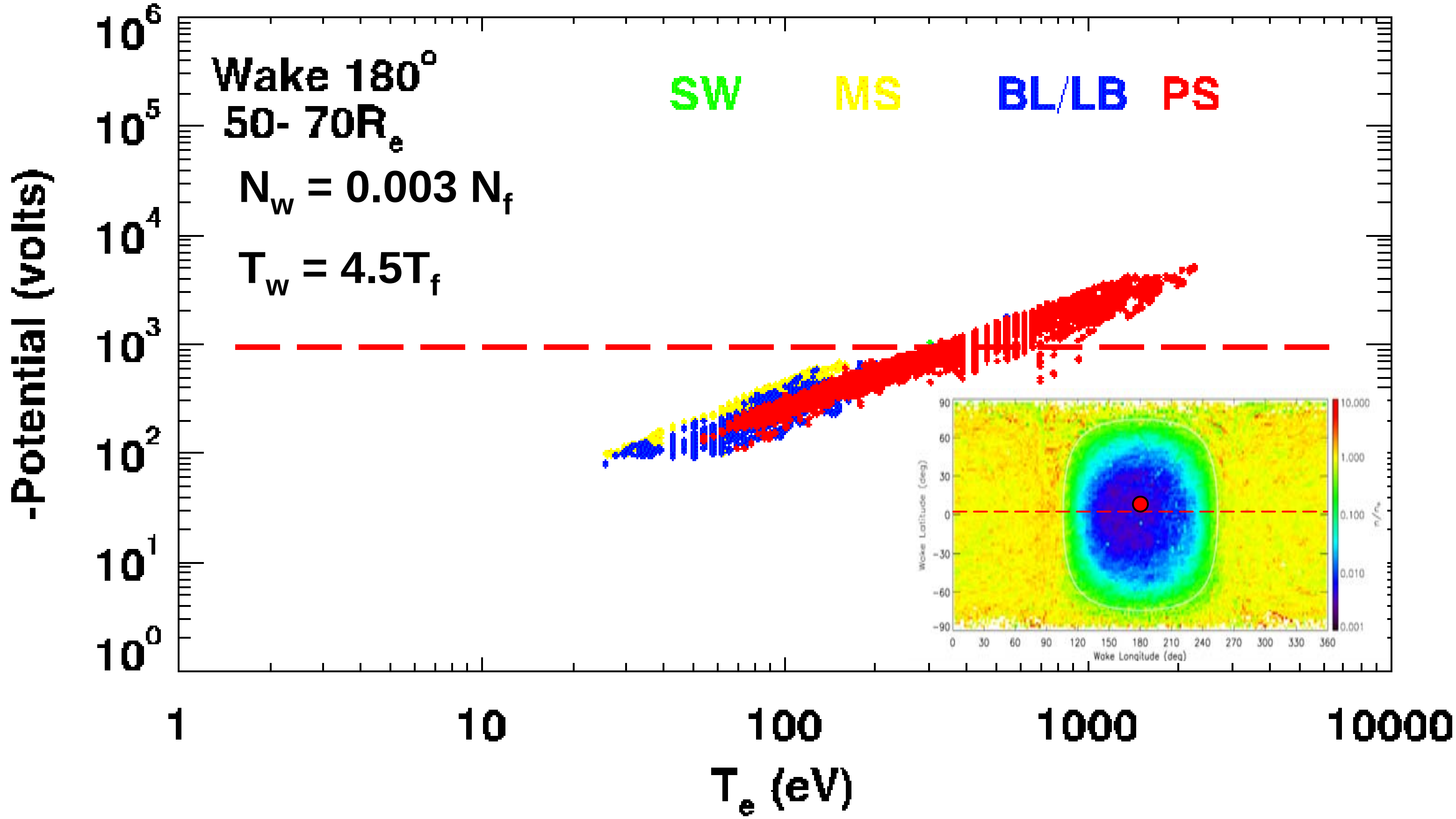
Assumes: $N_i \sim N_e$

$T_i \sim T_e$

Wake Potentials: 180º

50-70 R_e

$$\phi = -\frac{kT_e}{e}\ln\left[\left(\frac{T_e}{T_i}\frac{m_i}{m_e}\right)^{1/2}\left(\frac{n_e}{n_i}\right)\right]$$



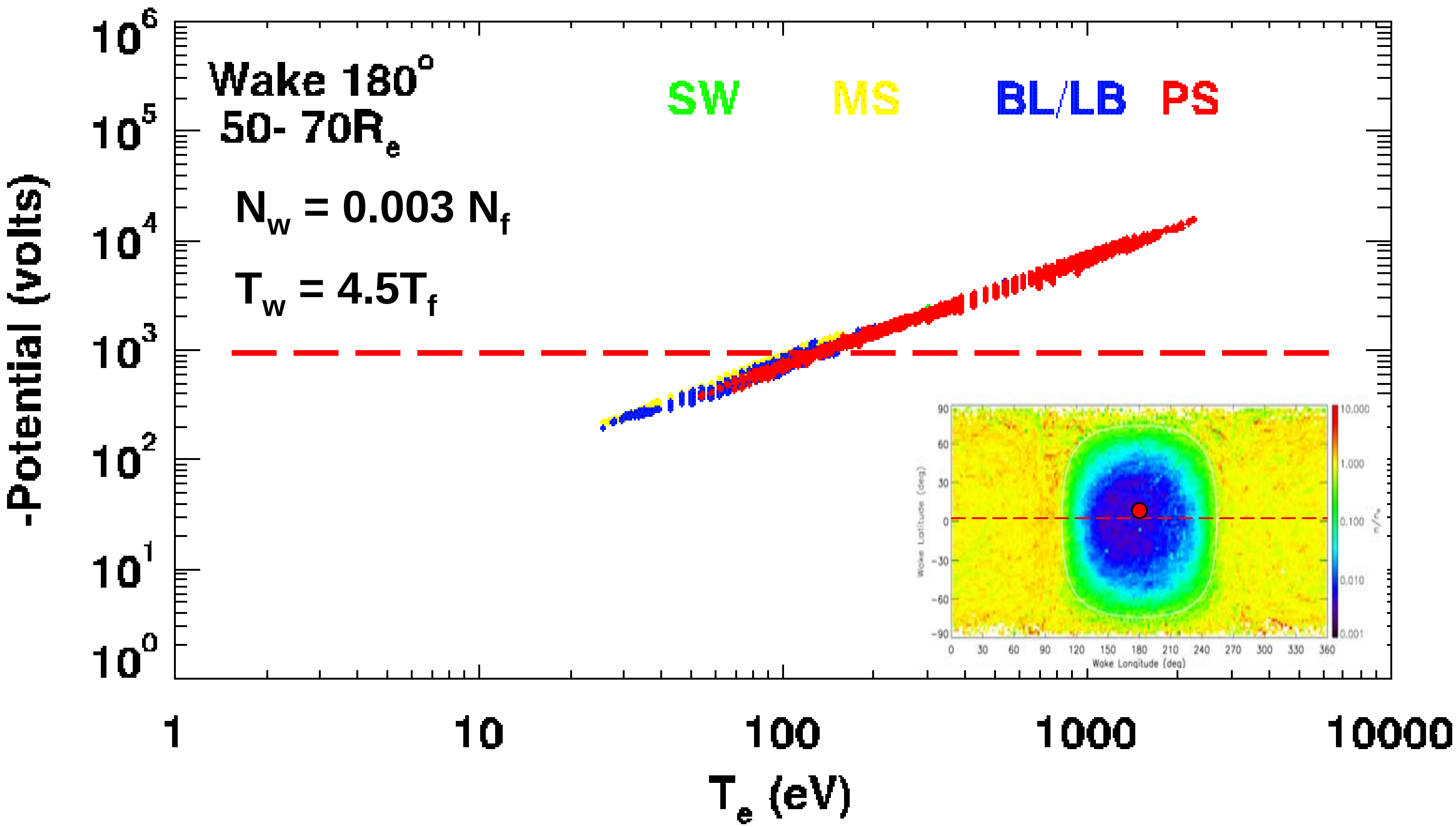
Assumes: $N_i \sim N_e$

$T_i \sim T_e$

Wake Potentials: 180º

50-70 R_e

$$\phi = -\frac{kT_e}{e}\ln\left[\left(\frac{T_e}{T_i}\frac{m_i}{m_e}\right)^{1/2}\left(\frac{n_e}{n_i}\right)\right]$$



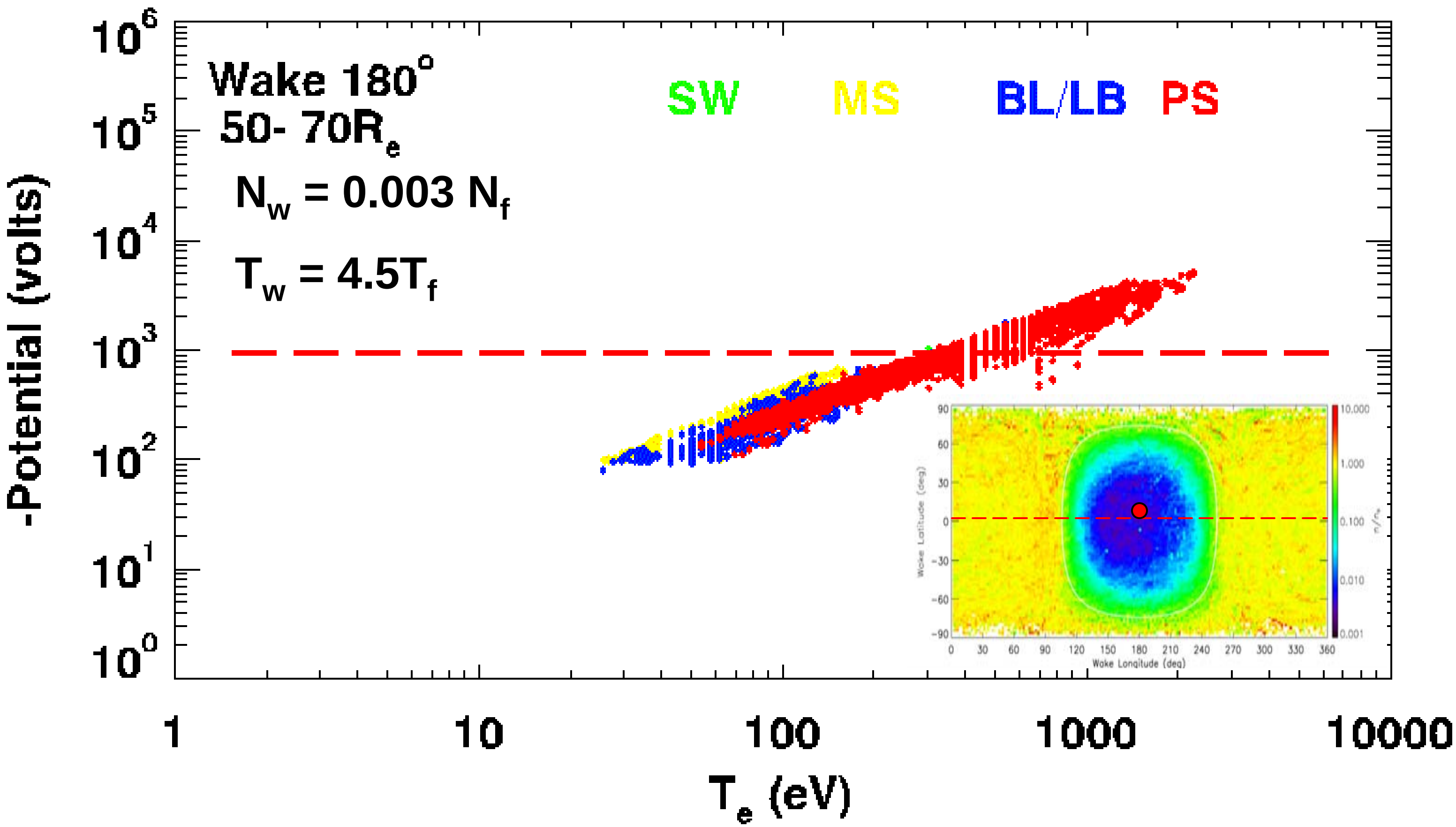
Assumes: $N_i \sim 0.1N_e$

$T_i \sim 0.01T_e$

Wake Potentials: 180º

50-70 R_e

$$\phi = -\frac{kT_e}{e}\ln\left[\left(\frac{T_e}{T_i}\frac{m_i}{m_e}\right)^{1/2}\left(\frac{n_e}{n_i}\right)\right]$$



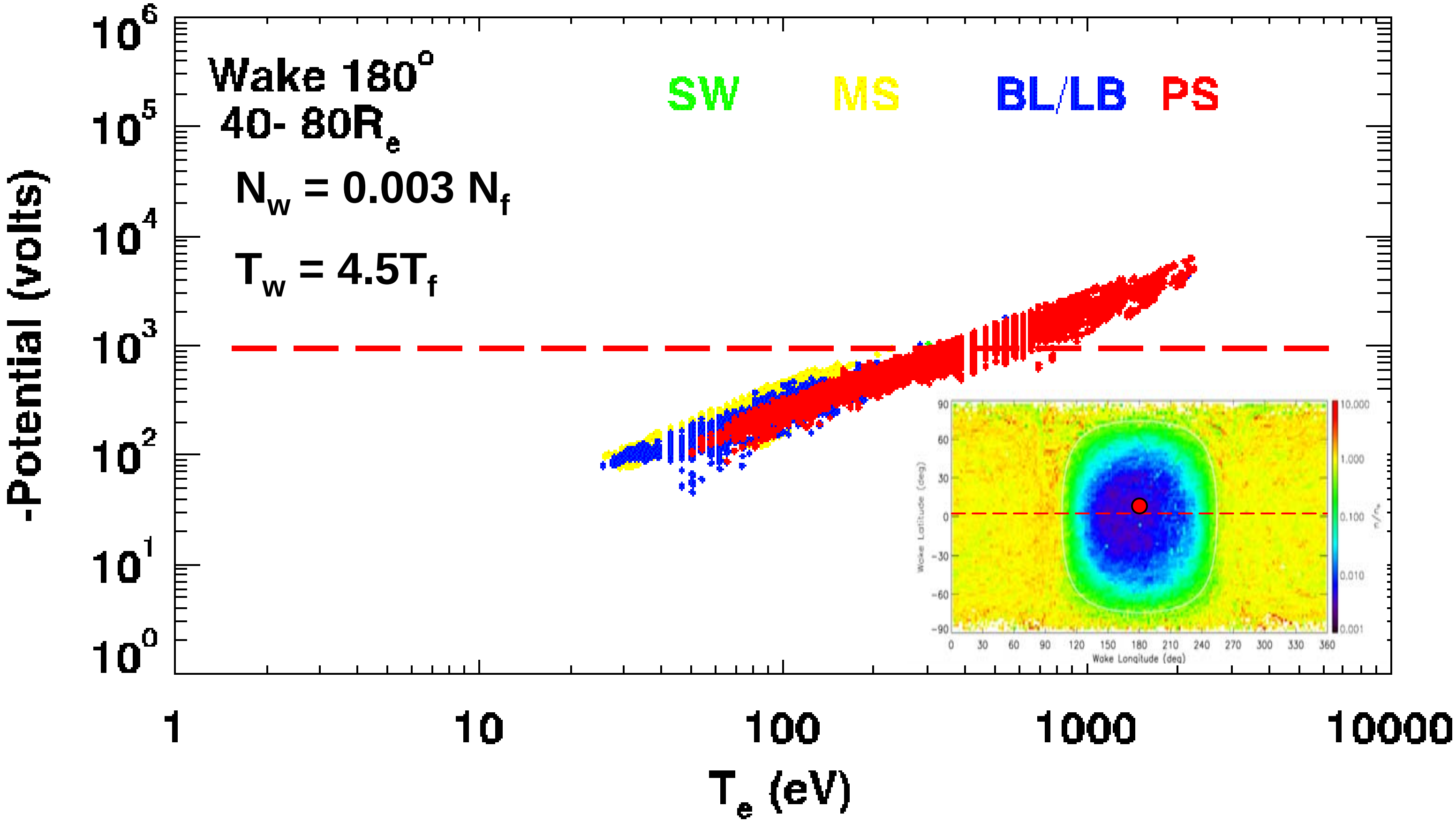
Assumes: $N_i \sim N_e$

$T_i \sim T_e$

Wake Potentials: 180º

40-80 R_e

$$\phi = -\frac{kT_e}{e}\ln\left[\left(\frac{T_e}{T_i}\frac{m_i}{m_e}\right)^{1/2}\left(\frac{n_e}{n_i}\right)\right]$$



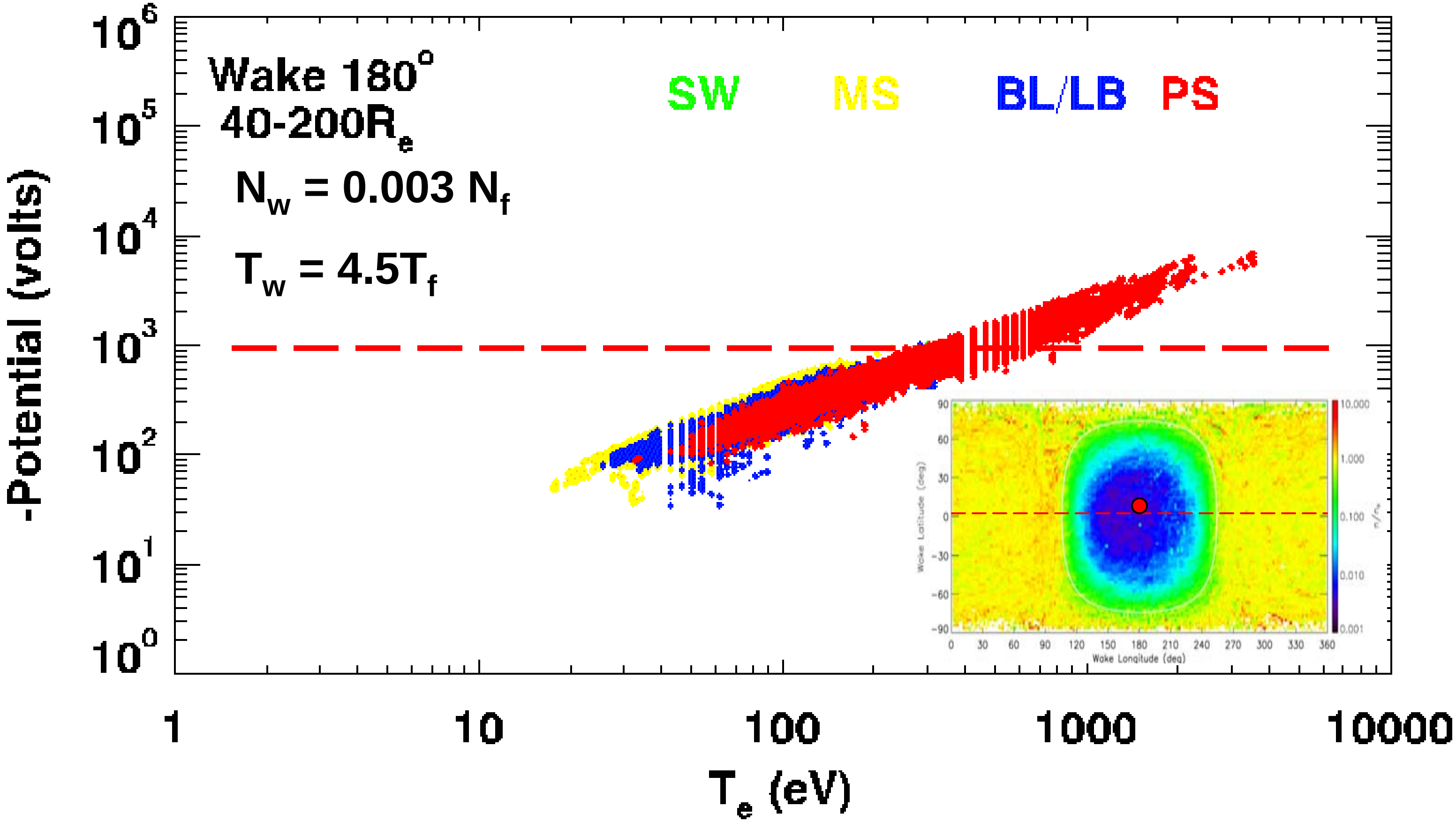
Assumes: $N_i \sim N_e$

$T_i \sim T_e$

Wake Potentials: 180º

40-200 R_e

$$\phi = -\frac{kT_e}{e}\ln\left[\left(\frac{T_e}{T_i}\frac{m_i}{m_e}\right)^{1/2}\left(\frac{n_e}{n_i}\right)\right]$$

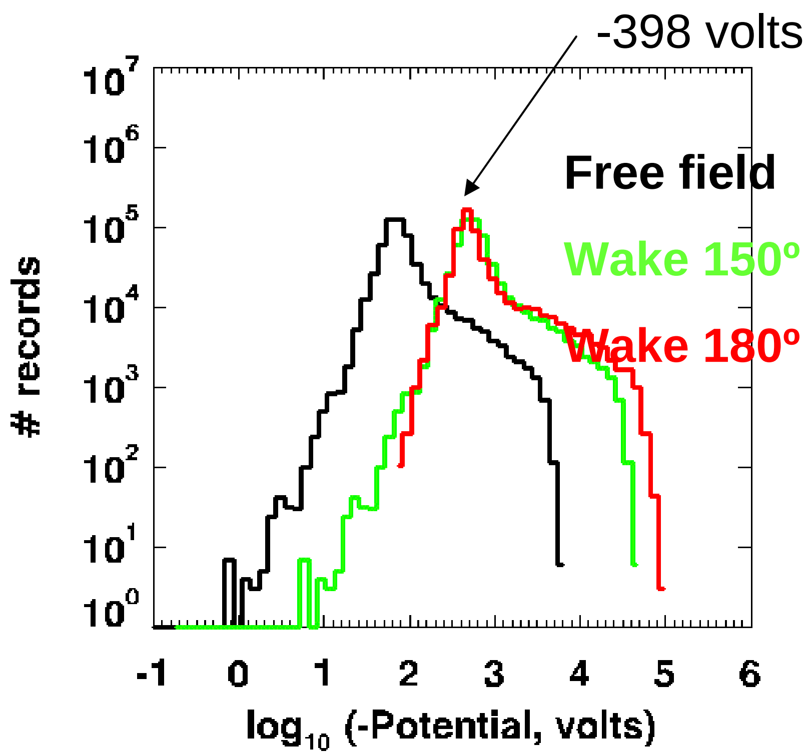


Assumes: $N_i \sim N_e$

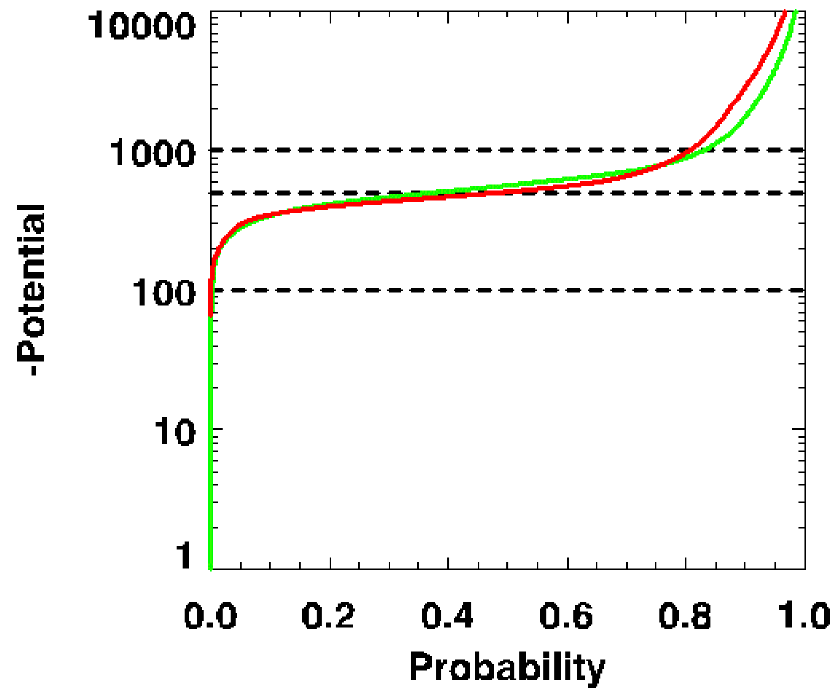
$T_i \sim T_e$

Surface Potential Distributions

Potential distributions



Cumulative Probability



All lunar relevant environments combined

~50% ≤ -500 volts

~15% ≤ -1000 volts

Lunar Surface Charging Observations

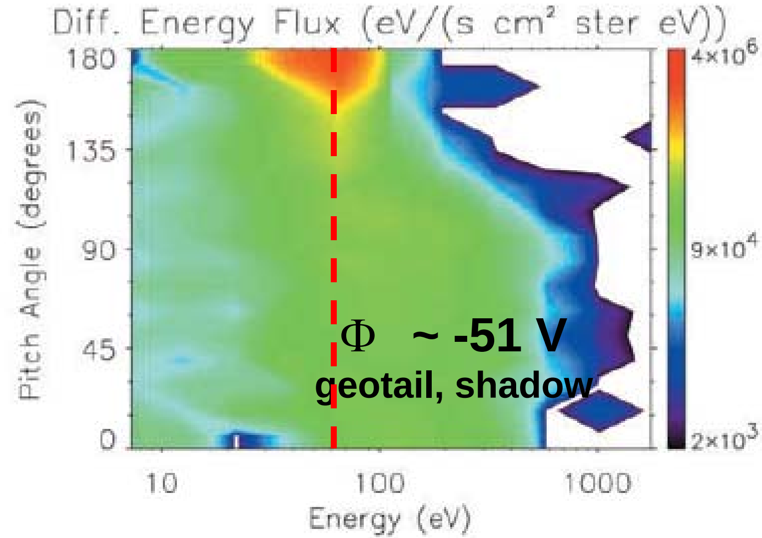
Lunar Prospector

20-115 km

Spacecraft potentials

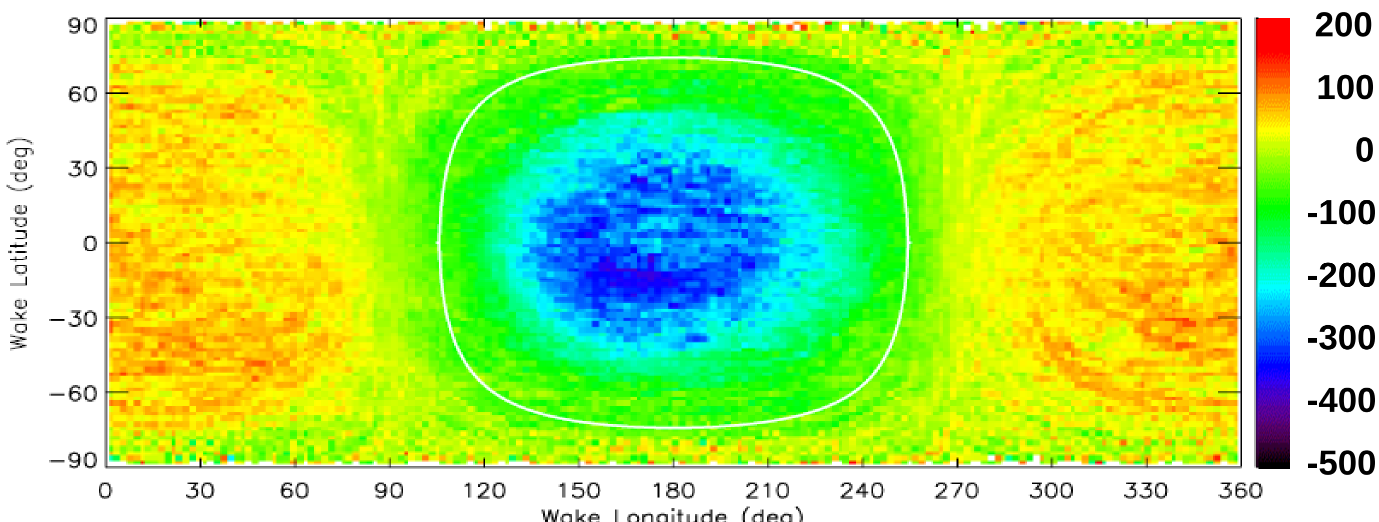
day +10 V to +50V

night -100 V to -400 V



[*Halekas et al.*, 2002]

$\Phi_{surface}$



-398 volts

[*Halekas et al*. 2005b]

Summary

- Results from preliminary evaluation of extreme charging environments show:
  - Potentials of objects exposed to lunar plasma environments at lunar distances charge negative (in darkness) to values of
  - Mean ~ 100's volts negative ~50% $\leq$ -500 volts
  - Extremes ~1000's volts ~15% $\leq$ -1000 volts

Kilovolt potentials occur sufficiently frequently to be of interest to lunar system design

- Future work
  - Expand database
  - Evaluate charging for candidate spacecraft using 3-D surface charging models including secondary electron emission effects